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GEOLOGIC CAUSES AND POSSIBLE PREVENTIONS OF ROOF FALL IN ROOM-AND-PILLAR COAL MINES

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U.S. Geological Survey

Prepared by the United States Geological Survey in cooperation with the Pennsylvania Geological Survey

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PREFACE

Today, we see a growing awareness in our nation of the importance of coal and forsee it playing a significant role in the solution of our energy crisis. The coal-mining process, therefore, becomes a vital link between this natural resource in the ground and the production of energy.

Coal recovery by mining has been hampered by certain technological problems, many of them solvable. The more data and information available, the easier it is to recognize and avoid problem areas entirely or to take the necessary steps toward reducing the problem to a minimum.

This report presents geologic information relating to the causes of shale roof falls, a major hazard in underground mining, and suggests ways to minimize this danger. The data have been gathered in active mining areas of Greene County, Pennsylvania; similar types of information and their application can be of great use in a wide variety of locations and situations.

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GEOLOGIC CAUSES AND POSSIBLE PREVENTIONS OF ROOF FALL IN ROOM-AND-PILLAR COAL MINES

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ABSTRACT

Severe and frequent roof falls of shale are the major hazard in underground mining in the room-and-pillar Pittsburgh coal mines of southwestern Pennsylvania. Several structural and sedimentary features directly affecting shale roof stability have been identified by core drilling, geologic mapping, and mapping roof falls in an area of active underground mining in eastern Greene County, Pennsylvania.

Mine maps of roof falls show two patterns: (1) **unidirectional**, in which roof falls are confined to passageways parallel to the northeast-trending butt cleat in Pittsburgh coal, and (2) **bidirectional**, in which roof falls show no preferred orientation with respect to passageway or cleat directions. Unidirectional roof falls are clearly related to northeast-trending sets of tension or release-type joints in the shale roof and overburden rocks. Bidirectional roof falls occur in zones of disrupted shale that are marginal to the edges of thick lenses of channel-fill sandstone overlying the coal; this type of shale roof is much weaker and much more difficult to control. The marginal zones are as much as several miles long, but their maximum width is about 500 feet.

Significant reductions in the incidence of unidirectional roof fall have been noted after mine haulageways and workings were turned oblique to the northeast-trending set of joints. The incidence of bidirectional roof fall may be reduced by crossing the marginal zones at right angles and by leaving longitudinal pillars to support the roof in the marginal zones.

INTRODUCTION

Roof falls of shale are the major hazard in room-and-pillar coal mines of southwestern Pennsylvania. Many published and unpublished investigations have been made and roof falls have been attributed to a variety of causes; but to date, there are no satisfactory explanations why roof falls occur in some areas of shale roof and not in others. This suggests that the geologic causes are complex and that important geologic factors have been overlooked.

In eastern Greene County, southwestern Pennsylvania (Plate 1), the Pittsburgh coal bed is 400-600 feet below the level of surface drainage. Mining has been very extensive in this area. More than 500 exploratory holes have been drilled to the base of the Pittsburgh coal, and the surface geology has been mapped in detail at a scale of 1:24,000 (Kent, 1969, 1971, 1973; Roen, 1970, 1973). The volume of information accumulated on sedimentary and structural features of rocks overlying the Pittsburgh coal is perhaps larger in this area than in most parts of the State, and much of this information is relevant to study of the problem of roof falls.

Roof falls in mines in Greene County show two distinct patterns: (1) In some mine areas where shale directly overlies the Pittsburgh coal, nearly all roof falls occur along northeast-trending mine passageways parallel to the butt cleat direction in the coal. Roof falls showing this linear pattern are here termed *unidirectional* roof falls. (2) In other mine areas where shale overlies the coal, but where thick sandstone lenses are known to overlie the coal nearby, the severe and frequent roof falls that occur in the shale roof have no uniform orientation relative to cleat or passageways. Roof falls showing this pattern are here termed *bidirectional* roof falls. In the places where both factors are present, their effects cannot be clearly separated.

The purpose of this report is to outline probable cause and effect relationships (unidirectional roof fall is related primarily to joints, and bidirectional roof fall is related primarily to the presence nearby of sandstone channel deposits in rocks overlying the Pittsburgh coal), and to report steps taken which have minimized rock falls attributed to these causes.

ACKNOWLEDGEMENTS

The author is indebted to the late Thomas A. King and other officers of the U.S. Steel Corporation, and to J.M. Vonfeld, Exploration Manager, Consolidation Coal Company, for use of core-log data in the area of this geologic study. He is also grateful to Roger C. Parsons, Senior Research Engineer, Continental Oil Company, who gave freely of his knowledge concerning the geologic aspects of the roof-fall problem in a mine south of the area of this study.

STRATIGRAPHY

INTRODUCTION

In this study, attention was given exclusively to the sequence of beds between the base of the Pittsburgh coal and the base of the overlying

Sewickley coal. According to the stratigraphic nomenclature for Upper Pennsylvanian and Lower Permian rocks in southwestern Pennsylvania, as revised by Berryhill and Swanson (1962), this sequence of beds includes the following members of the Pittsburgh Formation: the Lower Member (from the base of the Pittsburgh coal to the base of the Redstone coal), the Redstone Member (from the base of the Redstone coal to the base of the Fishpot coal), and the Fishpot Member (from the base of the Fishpot coal to the base of the Sewickley coal).

Throughout this report, repeated references are made to the informal term "Pittsburgh sandstone." The name Pittsburgh sandstone, as used by Piper (1933), is widely applied in local usage throughout southwestern Pennsylvania to identify a massive sandstone unit, in part consisting of sandstone-filled channels, which occurs just above the Pittsburgh coal bed. In the revised stratigraphic nomenclature of Berryhill and Swanson (1962) this unit is identified as a sandstone in the Lower Member of the Pittsburgh Formation. However, in places the Redstone coal has been scoured out and later filled in by sandstones, and some thicker sandstones also fill scours cutting out the Fishpot coal. Under some circumstances, formal stratigraphic nomenclature is difficult to apply. The lower parts of such channel-fill sandstones may be said to represent the Lower Member of the Pittsburgh Formation, and the middle and (or) upper parts may represent the Redstone and (or) Fishpot Members, but the members cannot be separated nor can they be defined. To further complicate the problem, it is likely that the channel-fill sandstone that rests on the Pittsburgh coal is younger than the adjoining rocks of the Lower Member and the Redstone Member and perhaps even part of the Fishpot Member.

GENERAL FEATURES

Throughout the area (Plate 1) the Sewickley coal is a persistent bed about 120 feet above the Pittsburgh coal. Variations in the interval between the two beds are shown in Figure 1A. The upper third of the interval consists mainly of limestone; the middle third consists of shale and limestone; and the lower third consists either of shale and limestone or of thick lenses of the Pittsburgh sandstone which locally may make up most of the sequence between the two coals.

Consequently, the greatest lateral contrast in rock types in the interval occurs in the lower third where layers of shale and limestone grade abruptly into or terminate abruptly against thick lenses of the Pittsburgh sandstone. These three disparate rock types form the roof rock of the Pittsburgh coal bed.

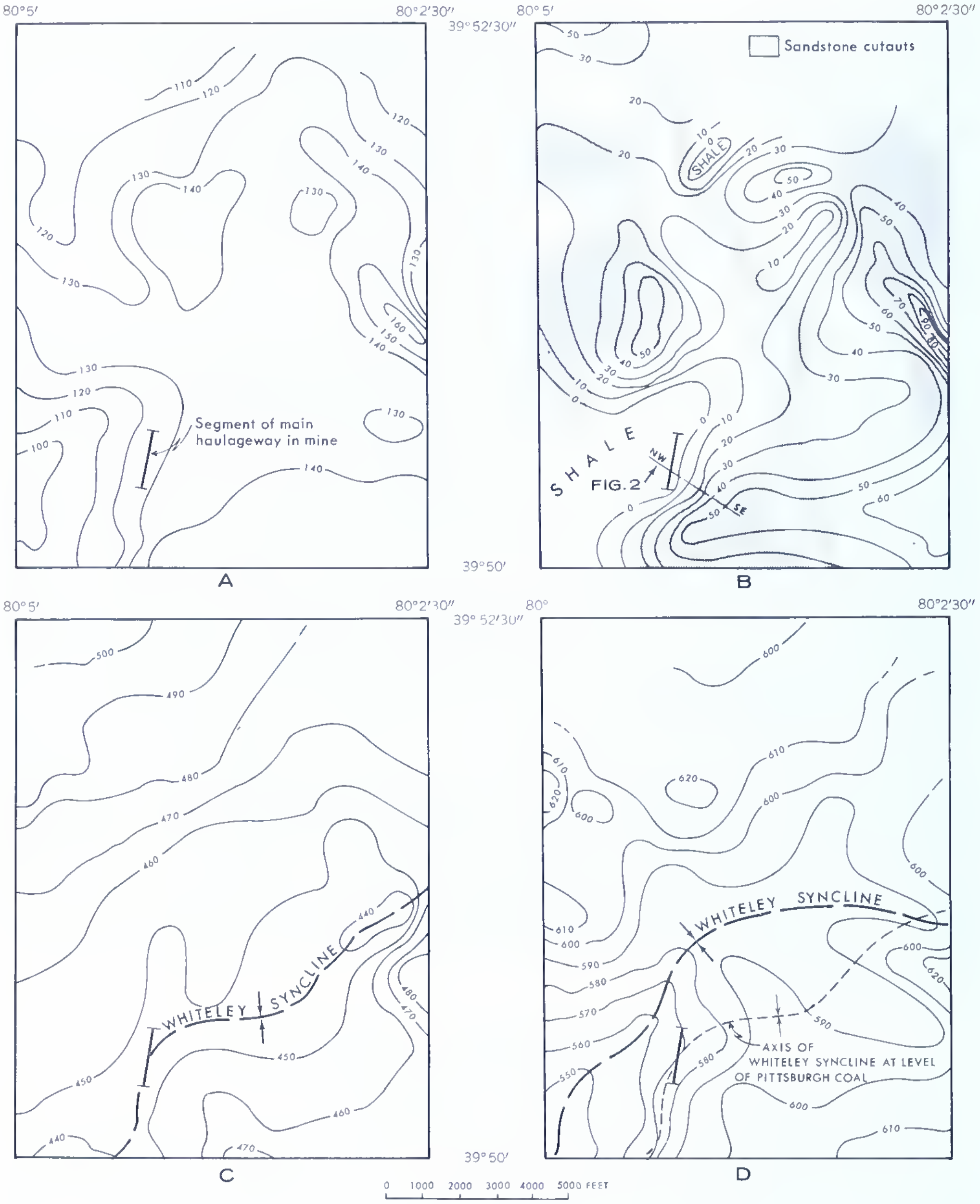
80°5′
80°2′30″
39°52′30″
39°50′
80°
Sandstone cutouts
Segment of main haulageway in mine
SHALE
FIG. 2
NW
SE
WHITELEY SYNCLINE
AXIS OF WHITELEY SYNCLINE AT LEVEL OF PITTSBURGH COAL
A
B
C
D
0 1000 2000 3000 4000 5000 FEET

Figure 1. Subsurface sedimentary and structural features in the sequence of rocks between the Pittsburgh and Sewickley coal beds in the north-central part of the Garards Fort quadrangle, southeastern Greene County (see Plate 1). Contour interval, 10 feet; datum is mean sea level. A. Isopach map of interval from base of Pittsburgh coal to base of overlying Sewickley coal. B. Isopach map of Pittsburgh sandstone (as used by Piper, 1933). C. Structure contour map, base of Pittsburgh coal. D. Structure contour map, base of Sewickley coal.

PITTSBURGH SANDSTONE

Distribution

The Pittsburgh sandstone as used by Piper (1933) extends in a northwest-trending belt 4-6 miles wide from Monongalia County, West Virginia, into southeastern Greene County, Pennsylvania. The part of the belt shown in Figure 1 directly overlies the Pittsburgh coal. Outside of this Pittsburgh sandstone belt, the sequence of rocks between the Pittsburgh coal and the overlying Sewickley coal consists of shale intercalated with beds of limestone.

The Pittsburgh sandstone ranges in thickness from a featheredge to as much as 80 feet. The thicker deposits, typically about 60 feet thick, are lens shaped with irregular bases. Many of the lenses are separated from the underlying coal by as much as 30 feet of shale, and others cut into or through the Pittsburgh coal. Laterally, many lenses terminate abruptly against shale, but a few thin gradually to extinction in shale. At a few places in the Pittsburgh sandstone belt the sandstone is absent.

Pattern of Deposition

The lower part of the Pittsburgh sandstone was deposited in a complex system of braided stream channels developed at different times following deposition of (Pittsburgh) peat. Some of the channels were completely filled with sand, and, as the influx continued in places, the sand spread out over the surrounding area as a sheetlike deposit (Figure 3).

The number of anastomosing sandstone-filled channels composing the lower part of the Pittsburgh sandstone could not be determined at most places, because the widths of the channels are generally less than the spacing of exploratory drill holes. Underground mine workings are also rather widely spaced, and mine maps of these workings indicate only where sandstone cutouts were encountered. Consequently, only those sandstone-filled channels that cut out some or all of the underlying Pittsburg coal beds are shown in Plate 1, and there is only an incomplete record of sandstone-filled channels that rest on or are just above the coal bed. Isopachs showing the thickness of the Pittsburgh sandstone (Plate 1) were spaced evenly between core-hole data points, in accordance with the common method of preparing isopach maps from point control; however, this method tends to smooth out abrupt irregularities in sandstone thickness, to obscure small channels, and to mask any abrupt terminations of sandstone against shale.

In the small area of Figure 1B, the Pittsburgh coal has been mined extensively, and exploratory drill holes were more closely spaced than in the larger area of Plate 1. Consequently, the variations in thicknesses of channel-fill sandstone and the terminations of sandstone against shale are more accurately delineated on Figure 1B. The distribution of sandstone cutouts (Figure 1B) suggests the braided pattern that is believed to characterize the Pittsburgh sandstone deposits throughout the entire sandstone belt.

Compaction Effects on Interval Thickness

The amount of compaction that took place in the sequence of rocks between the base of the Pittsburgh coal and the base of the Sewickley coal is indicated by the experimental data in Table 1. Experimental data on the compactability of carbonates is unavailable, but the limestone beds are generally very argillaceous and the compactability of a "clayey lime" might be similar to that of a clay or mud.

Table 1. Average Compactability, in Percent Reduction of Original Bulk Volume, of Different Types of Sediment at Different Depths of Burial

From Athy (1930), Raistrick and Marshall (1939), Weller (1959)

Sediment type	Depth of burial (in ft.), and corresponding percent reduction						Rock type after compaction
	0-50	1,000	2,000	3,000	4,000	5,000	
Clay	—	20	35	40	—	—	Claystone.
Mud	—	25	35	41	46	50	Mudstone or shale.
Mud	0-23	31	36	—	—	45	Mudstone or shale.
Peat	80	90	95	—	—	—	Coal.
Sand	11	—	—	—	—	13[1]	Sandstone.

[1] Calculated from data given by Athy (1930) and Weller (1959).

The original overburden on the Pittsburgh coal in eastern Greene County was at least 2,000 feet. At that depth, as shown in Table 1, the bulk volume and, therefore, the thickness of clay and mud is reduced an average of 35 percent in the transformation to claystone, mudstone, and shale; that of peat is reduced 95 percent in the transformation to coal; and that of sand is reduced only about 11 percent in the transformation to sandstone. Table 1 also indicates that clay and mud continue to compact as overburden thickness increases, whereas peat and sand reach near-maximum compaction during initial stages of burial.

Because the compaction ratio from mud to shale is greater than the ratio from sand to sandstone, the interval between the base of the Pittsburgh coal and the base of the Sewickley coal tends to be smaller in areas where the Pittsburgh sandstone is thin or absent. This relation can be demonstrated in a general way by comparing Figures 1A and 1B.

At a few places, typified by locality X (Plate 1), an unusually thick sandstone sequence characterizes an unusually thin Pittsburgh to Sewickley coal interval. This anomalous relation might be explained if, following the original deposition of mud, a deep channel was eroded into the semiconsolidated sediment and only partly filled with sand. The Sewickley peat was subsequently deposited in the depressions left by the partly filled channel.

Where the recorded thickness of Pittsburgh sandstone is on the order of 50 feet, where the base of this sandstone unit is near the top of the underlying (Pittsburgh) coal bed, and where the Pittsburgh to Sewickley coal interval is less than 140 feet, it may be presumed that the form of the sandstone is chiefly that of a channel-fill deposit rather than that of a more uniformly distributed sheetlike deposit.

Compaction Effects on Marginal Zones

The effects of overburden and differential compaction are marked along the margins of sandstone-filled channels of Pittsburgh sandstone. During compaction, individual layers of claystone and mudstone are bent, stretched, and even broken around the relatively unyielding lenses of sandstone. These effects decrease away from the margins of sandstone-filled channels. The result of these effects is particularly well illustrated in a segment of a haulageway, the location of which is shown in Figure 1. The segment is about 200 feet northwest of the edge of a thick sandstone channel (see Figure 1B). Along this segment, shale roof is exposed by numerous roof falls, and the individual layers of claystone and mudstone that compose the roof are extensively buckled, contorted, fractured and sheared.

Marginal zones of deformed shale layers are as much as several miles long (see Plate 1). They are estimated to be from a few feet to about 500 feet wide depending on the thickness of the sandstone lens and the abruptness with which the sandstone lenses out in the enclosing shale. The sandstone-filled channels are sinuous in plan view, and they change in width and orientation accordingly. However, no significant distortion and crushing of shale would occur in areas where sandstone grades gradually into shale.

Some of the deformation of shale in marginal zones may have been produced by stresses that originated from lateral compression during folding. A sandstone lens in a matrix of less rigid shale under stress can be thought of as analogous to an object such as a steel bar in a slab of concrete under stress. A crude estimation of the effectiveness of stress differentials beyond the sandstone margins, and of the effective width of a marginal zone, can be derived from such studies as those of Goodier (1933); he concluded (p. 39) that at a distance of some four diameters

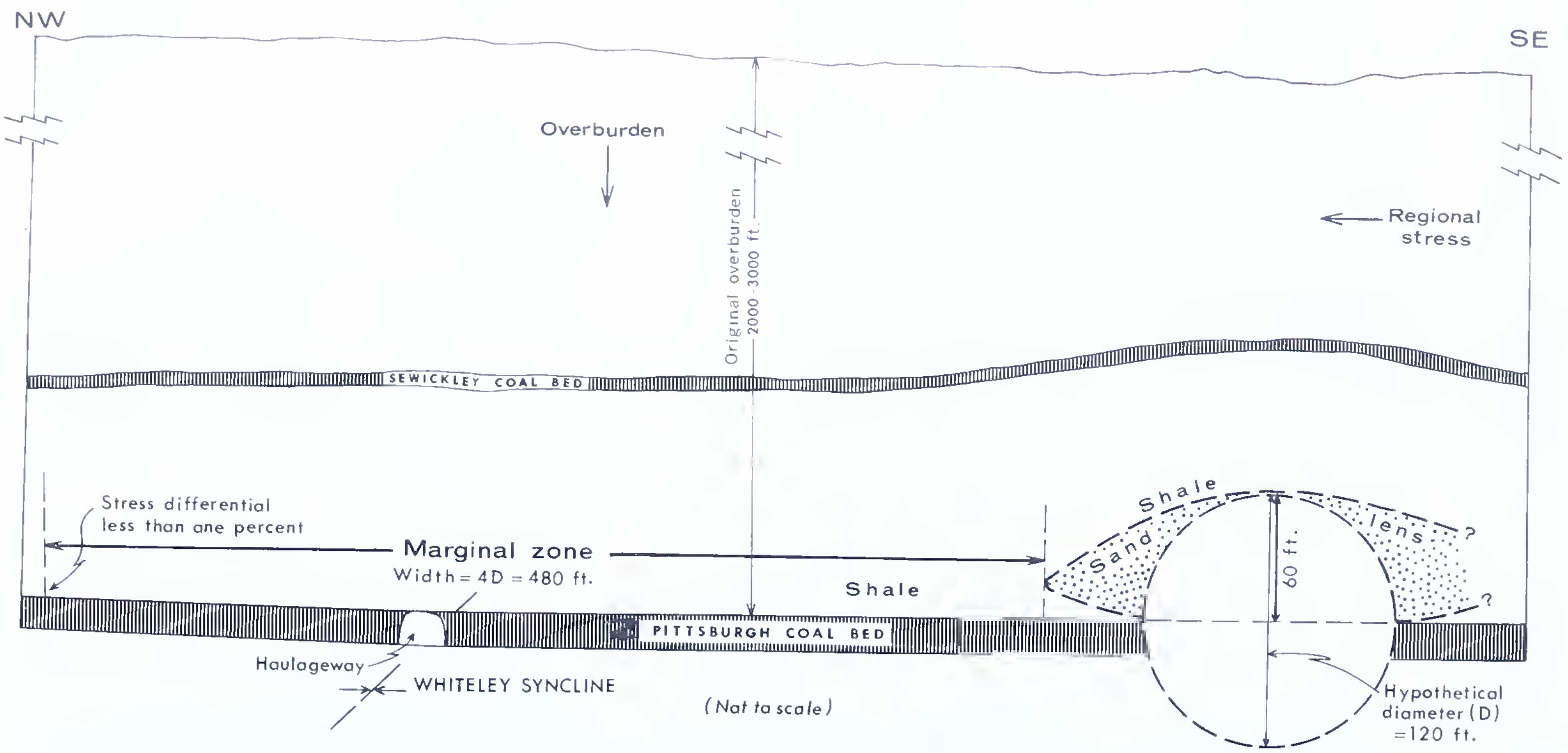

Figure 2. Diagrammatic section along line in Figure 1B showing position of mine haulageway with respect to sandstone lens to the southeast, and calculated width of marginal zone of disturbed shale.

from an inclusion such as a reinforcing rod in cement under stress, the stress distribution, which would be uniform without the inclusion, would be modified by no more than 1 percent. A lens of channel-fill sandstone that has a maximum thickness of about 60 feet can be considered to act as a rigid hemispherical body with a diameter of about 120 feet (Figure 2). By analogy with Goodier's (1933) reinforcing rod, the maximum width of the zone over which the stress differential would drop to 1 percent is four times the diameter of the hemisphere, which is eight times the thickness of the lens, or about 480 feet.

Accordingly, widths of marginal zones are scaled in at about 500 feet on Plate 1 inasmuch as the isopachs of Pittsburgh sandstone indicate a maximum thickness of about 60 feet. However, because the rule of thumb expressed by the 8:1 ratio applies only to lenses of channel-fill sandstone that thin abruptly at their margins, a width of 500 feet is about the maximum to be expected.

STRUCTURE

Eastern Greene County lies just to the east of the major axis of the Appalachian basin synclinorium. The regional dip of the rocks is generally less than 1°, and slightly more in a few local areas. In the area shown on Plate 1 the amplitude of the Bellevernon anticline is about 300 feet and that of the Fayette anticline, to the southeast, is about 650 feet.

FOLDS

The Bellevernon anticline, the Fayette anticline, and the intervening Whiteley syncline trend about N40E across the area. Structural dips on the flanks of these anticlines generally are less than 1° although some dips, probably reflecting the effects of differential compaction, locally exceed 5°.

As illustrated by Figures 1C and 1D, the trends of the fold axes are markedly sinuous in detail, and fold axes in different coal beds or other horizons do not precisely correspond due to unsystematic changes in the thickness of intervals between beds (Figure 1A). The effects of differential compaction and of irregularities on the surface of deposition of the coal, which are superimposed on the broad-scale tectonic folds, combine to produce many minor irregularities in the structure contours (Figures 1C and 1D).

During folding, the thick lenses of Pittsburgh sandstone must have resisted compressive forces (from the southeast) more strongly than the enclosing shale. Resulting differential movements may have additionally crushed and distorted shale adjoining the sandstone buttresses. Any such crushing and distortion would have been most intense in the shale along the northwest and southeast sides of sandstone lenses, which were the sides perpendicular to the direction of compressive force.

FAULTS

Faults are relatively rare in the rocks of southwestern Pennsylvania. In the area shown on Plate 1, almost all of the few faults that have been observed strike parallel to fold axes and fault planes commonly dip toward the axes of synclines; reverse faulting is most common and displacements are generally less than 5 feet. The orientation of these faults and relative movements suggest a wedging action resulting from, and contemporaneous with, folding.

The only fault shown on Plate 1 is an exception to the general rule. It is a strike-slip, left-lateral fault zone extending for a distance of several miles in the Carmichaels quadrangle. This fault strikes about N55W, in the direction of the Set B joints of Nickelsen and Hough (1967, Plate 3) and within the northwest section of joint trends noted in the area shown in Plate 1. The rocks on the northeast side of this fault seem to have moved to the northwest relative to those on the southwest side, as suggested by apparent displacements of the Brownsville anticline and the Whiteley-Port Royal syncline.

JOINTS AND CLEAT

Regional Pattern

Trends of major joint sets in southern New York State and northern Pennsylvania (the northern part of the Appalachian basin) were determined by Parker (1942), and major joint sets in western Pennsylvania by Nickelsen and Hough (1967).

Parker (1942) showed that a double set of joints intersected at angles of 10°-30° (Set I), and had a mean strike trending approximately perpendicular to fold axes; and that a single set of joints intersected the mean strike of the double set at approximate right angles (Set II) and trended approximately parallel to fold axes. Parker (1942, p. 395-396) described Set I joints as remarkably planar, and interpreted them to be the result of shearing stresses. He (Parker, 1942, p. 396-397) described Set II joints as curved and irregular, having a rough, torn appearance, and attributed them to tensional stresses.

Nickelsen and Hough (1967, Plate 3) described and mapped three major sets of joints (B, C, and "I") in the coal-bearing rocks of southwestern Pennsylvania. In their nomenclature, Set B joints (in shale) strike about N55W; Set C joints (in shale) strike about N80W; and Set "I" joints (the face cleat in coal) strike about N70W. The trend of Sets B, C, and "I" joints is approximately perpendicular to fold axes. Nickelsen and Hough (1967, p. 613) stated that joints belonging to Sets B, C, and "I" conform descriptively to the planar Set I joints of Parker (1942), but they preferred to call them "systematic" joints. They also noted joints belonging to sets which intersect Sets B, C, and "I" at approximate right angles, which they called "nonsystematic." These sets of nonsystematic joints conform to the nonplanar Set II joints of Parker (and include the butt cleat in coal). Intersecting sets of systematic and nonsystematic joints are shown diagrammatically on Plate 1, where, for convenience, sets of nonsystematic joints are called Sets B′, C′, and I′.

Greene County Pattern

In the area shown on Plate 1, two major sets of joints in shale, sandstone, and limestone were measured during the present work: (1) a northwest-trending set oriented in the N55-85W sector; and (2) a northeast-trending set oriented in the N5-35E sector. Joints belonging to the northwest-trending set correspond to the systematic joints of Nickelsen and Hough (1967) and include their Sets B and C, and those belonging to the northeast-trending set correspond to their nonsystematic joints.

In both outcrops and mines the face cleat of the Pittsburgh coal is oriented in the N70-75W sector and the butt cleat is oriented in the N15-20E sector. These well-defined cleat directions correspond very well with directions observed regionally by Nickelsen and Hough (1967); and the narrow ranges of directions fall within the wider ranges of directions of joints in shale, sandstone and limestone.

The northwest-trending joints and the face cleats commonly are planar, smooth, parallel to each other, closely spaced, and crosscut other joint sets; whereas the northeast-trending joints and the butt cleats commonly are jagged, rough, curving, offset by other joint sets, and more widely spaced. Many of the northeast-trending joints terminate against joints of the more regular northwest-trending sets, and many curve abruptly and terminate against adjacent joints of the same northeast-trending set.

Origin and Age

The origin and age of joints and cleats have been discussed by Raistrick and Marshall (1939, p. 42-45), Parker (1942), Hubbert and Rubey (1959, p. 152-153), Hodgson (1961), Secor (1965), and Nickelsen and Hough (1967), among others.

The factors that seem most relevant to the association of joints and cleats with the roof-fall problem in Greene County are as follows:

(1) Vertical joints normal to bedding were formed very early in the diagenesis of the sediments.

(2) Sediments of the Appalachian basin were subjected to directional tectonic stress penecontemporaneously with diagenesis. This stress contributed to the development of fractures, and established regional direction patterns.

(3) Although affected by compressive stress, any or all joints may be tension- or release-type fractures. Joints approximately parallel to fold axes are almost certainly tension fractures.

(4) Concepts of origin adequately explain well-developed tension fractures at substantial depths in all coal basins.

(5) The face cleat in coal is most sensitive to, and indicative of, directional compressive stress.

(6) Cleats and joints form sequentially as follows: cleats in coal; joints in shale; joints in sandstone.

(7) The spacing of joints varies with rock type as follows: (a) cleats in coal are very closely spaced and well developed; (b) joints in shale are generally less than 1 foot apart, and are not so well developed as cleats in coal or as joints in limestone and sandstone; (c) joints in limestone are about 1 foot apart and are well developed; and (d) joints in sandstone are typically more than 1 foot apart and are well developed.

(8) The orientation and spacing of joints and cleats apparently do not change in the depth range available for observation, although the joints at depth may be tightly closed by the confining pressure.

THE ROOF-FALL PROBLEM

UNIDIRECTIONAL

Shale roof falls were prevalent along mine passageways oriented northeast, parallel to the butt cleat in a Pittsburgh coal mine that is about 10 miles north of the study area (J. Kepenich, oral commun., 1968). Roof falls along mine passageways oriented northeast were also prevalent in a Sewickley coal mine in the southeastern part of the area shown on Plate 1. Shale roof falls also occur frequently in a Pittsburgh coal mine southwest of the Pittsburgh sandstone belt (Plate 1); more than 90 percent of the roof falls mapped in that mine occurred along mine passageways oriented northeast, parallel to the butt cleat in the coal (R.C. Parsons, oral commun., 1969-1971). Roof falls occurring in a linear pattern along this northeast direction are referred to here as unidirectional.

The prevalence of unidirectional roof fall parallel to northeast-trending sets of joints is presumptive evidence that the joint sets create zones of weakness in the shale roof. Incipient northeast-trending tension fractures in the shale roof tend to open when stress is relieved during mining, and haulageways driven parallel to that principal direction of jointing are particularly exposed to a high incidence of roof fall.

BIDIRECTIONAL

Representative areas of frequent roof fall in the mine in southeastern Greene County are shown on Plate 1; the pattern of roof fall in these areas is bidirectional, having no uniform orientation relative to cleat or passageways. The mine roof in these areas is slumped, buckled, contorted, fractured, and sheared shale, and most of the areas are marginal to thick lenses of Pittsburgh sandstone.

Localities A and B, Plate 1, are segments of a marginal zone. The haulageway shown on Figure 1 is within this segment, and is estimated to be about 200 feet northwest of the edge of an abruptly terminating lens of channel-fill Pittsburgh sandstone (Figure 1B). The shale roof at locality A is along the northwest side of a thick sandstone buttress, and crushing of the shale roof may have been intense. (See discussion under "Folds.")

At locality C, Plate 1, the shale roof is highly contorted and structurally weak. Examination of the distribution of the Pittsburgh sandstone shows that the locality is surrounded by thick lenses of channel-fill sandstone that terminate abruptly in the shale, and that the area of roof shale is about 500 feet wide and 1,000 feet long. In this area, effects of differential compaction and crushing were at a maximum, and stress differentials decreasing away from the margin of one sandstone body would be reinforced by stress differentials increasing toward the margin of another. The combined effects are dramatically apparent, in that the highest incidence of roof falls was reported at this place in the mine.

At localities D and E (Plate 1), the mine workings were under shale roof, but the shale roof remained firm and roof falls were uncommon. Both of those localities are well outside the calculated 500-foot-wide marginal zone and, therefore, it is unlikely that the shale roof was appreciably affected by differential compaction, or that significant stress differentials developed.

Some geologic relations at locality Y (Plate 1) are shown in Figure 3. At this locality the roof rock over former underground mine workings in the Pittsburgh coal bed is exposed in cross section in the highwall of an abandoned strip mine, and the geologic relations are unusually plain. When this area was mined underground, a major roof fall occurred. A lens of channel-fill Pittsburgh sandstone directly overlies the Pittsburgh coal (Figure 3) and terminates abruptly against shale about 50 feet to one side of the mine entry. An adjoining marginal zone of contorted shale

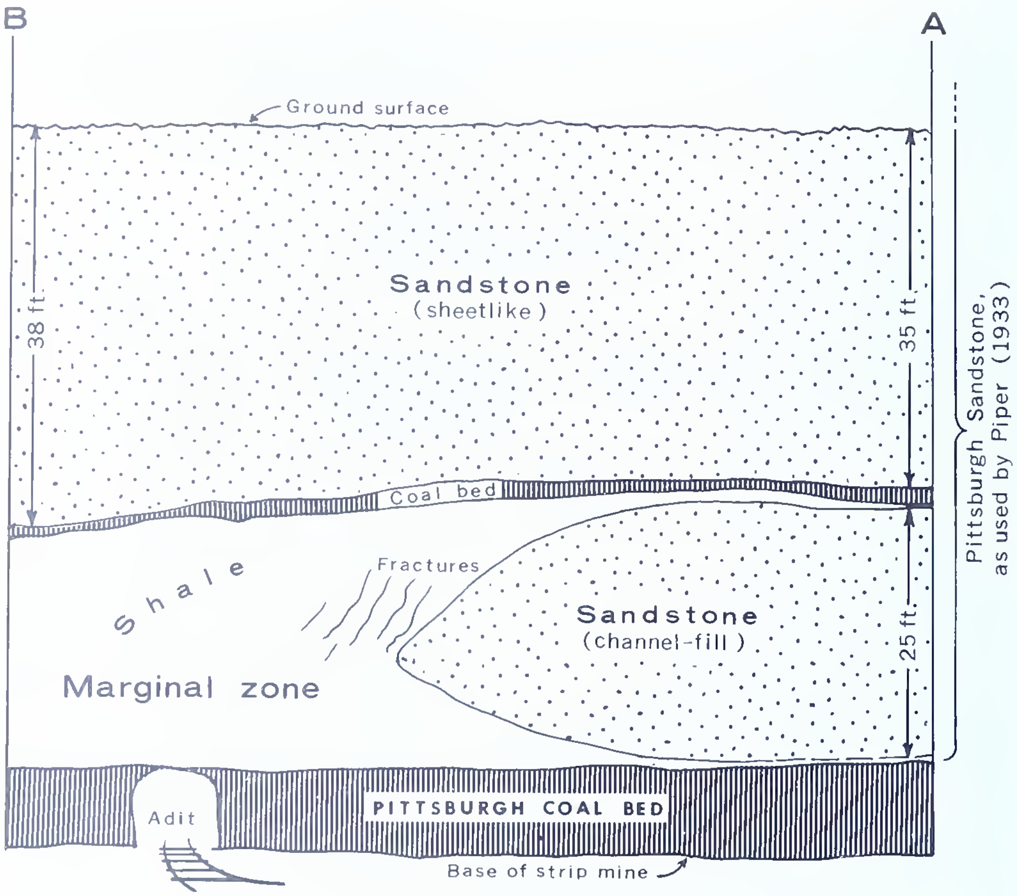

Figure 3. Geologic relations at field locality Y, south-central part of the Masontown quadrangle (see Plate 1). Sketch shows that the Pittsburgh sandstone, as used by Piper (1933), is composed of two sandstone units exposed in a northwest-facing highwall of a combination strip and underground mine in the Pittsburgh coal. When this area was part of an underground mine a major roof fall occurred in the adit.

extends outward from the channel-fill sandstone margin and over the mine adit.

Some areas of bad roof beneath a thick cover of Pittsburgh sandstone are indicated on Plate 1, in apparent contradiction to the general rule that such areas are safe. In some of these areas the Pittsburgh sandstone is believed to be a composite unit similar to that shown in Figure 3 where the lower part consists of channel-fill deposits and the upper part consists of sheetlike deposits. In isopach studies of the composite unit of Pittsburgh sandstone, thick sheetlike deposits of the upper part tend to mask locations of underlying channel-fill deposits and accompanying marginal zones of shale (Figure 3).

CONTROL OF ROOF FALL

The roof-fall hazard can be anticipated and minimized, in part, by proper orientation of mine workings on the basis of surface and subsurface mapping of structural and sedimentary features in the rocks that overlie the coal.

The incidence of unidirectional roof fall can be reduced if mine workings are oriented to bisect the angles formed by intersecting sets of major joints. In southwestern Pennsylvania a simple practical way to determine the optimum directions of mining to minimize roof-fall problems associated with joints is to bisect the angles formed by the intersecting face and butt cleats in the coal being mined. On this basis, optimum orientations of mine workings in southeastern Greene County are N30W and N60E.

Northeast-trending joints are everywhere present in southwestern Pennsylvania, but the degree to which northeast-trending tension fractures in the shale roof may be opened by stresses relieved during mining will vary from place to place. Consequently, the effectiveness of reorienting mine workings for the purpose of introducing partial control of unidirectional roof fall must be evaluated on the basis of an overall, long-term reduction in the incidence of roof falls. For example, mining directions in the Sewickley coal mine (Plate 1) were reoriented (1967-68) to about 45° from face and butt cleat directions in Sewickley coal; and mining directions in a Pittsburgh coal mine about 10 miles north of the study area were reoriented (1969) to about 45° from face and butt cleat directions in Pittsburgh coal. To date (1972) significant reductions in the incidence of roof falls have been noted in both of those mines.

Bidirectional roof fall is more difficult to control. Main haulageways should be located outside of potentially hazardous marginal zones, but where marginal zones cannot be avoided, haulageways and mine workings should cross them at right angles, and longitudinal pillars and other supports should be amply provided. Long-term use of mine workings in marginal zones and long-term mining within a marginal zone and parallel to its trend should be avoided.

Marginal zones are localized and are difficult to find in advance of mining. In areas where thick sandstone cover on coal is suspected, extensive exploratory drilling will provide additional information on the locations of channel-fill sandstones, and mine maps of sandstone cutouts provide data on the trends of sandstone-filled channels which will help predict their positions in unmined areas. As roof bolts are installed during mining beneath a sandstone lens that rests directly on the coal, identification of the lithologies (sandstone versus shale) encountered in drilling for roof bolt emplacement may record a rise in the base of the overlying sandstone lens, which could warn of a possible marginal zone ahead.

Regional maps of the trends of sandstone-filled channels and sandstone belts establish the general pattern of the ancient channel system. Isopach maps of the interval between the top of the coal bed and the base of the first overlying sandstone would provide a better way to establish the existence and location of some marginal zones.

CONCLUSIONS

The distribution and frequency of roof fall in room-and-pillar coal mines in southwestern Pennsylvania can be related to structural and sedimentary features in rocks overlying the coal.

Unidirectional roof fall occurs along northeast-trending sets of tension joints in the shale roof over the coal. Unidirectional roof fall has been minimized by orienting mine workings about 45° from face and butt cleat directions in the coal.

Bidirectional roof fall occurs most commonly in zones of distorted shale on the margins of thick lenses of channel-fill sandstone. The distortion is a result of the markedly greater compactability of clay and mud compared to that of sand. As the sediments were differentially compacted, individual layers of shale were bent, stretched, and even broken around relatively unyielding lenses of sand, especially on the margins of sandstone-filled channels, where the compaction differential is greatest. Many of these marginal zones can be found by careful study of data obtained during development drilling and mining. The incidence of bidirectional roof fall may be reduced by orienting mine workings to cross marginal zones at right angles, and by leaving longitudinal pillars to support the roof in the marginal zones.

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------------	Geologic contact, dashed where approximate; dotted where inferred or covered
------↕·······	Anticline in Epler Formation; concealed below Cocalico Formation where short dashes are shown
------⌒------	Overturned anticline
------∪------	Overturned syncline
----U/D----81----	Fault, relative movement indicated by U (up) and D (down)
▼▼▼▼▼▼▼▼	Thrust fault, barbs on side of upper plate
8	Strike and dip of beds known to be right side up
20	Strike and dip of beds where it is not known which side is up
15	Strike and dip of overturned beds
15	Generalized strike and dip of bedding
20	Strike and dip of foliation
20	Strike and dip of cleavage
Ⓐ	Location of sample and/or quarry

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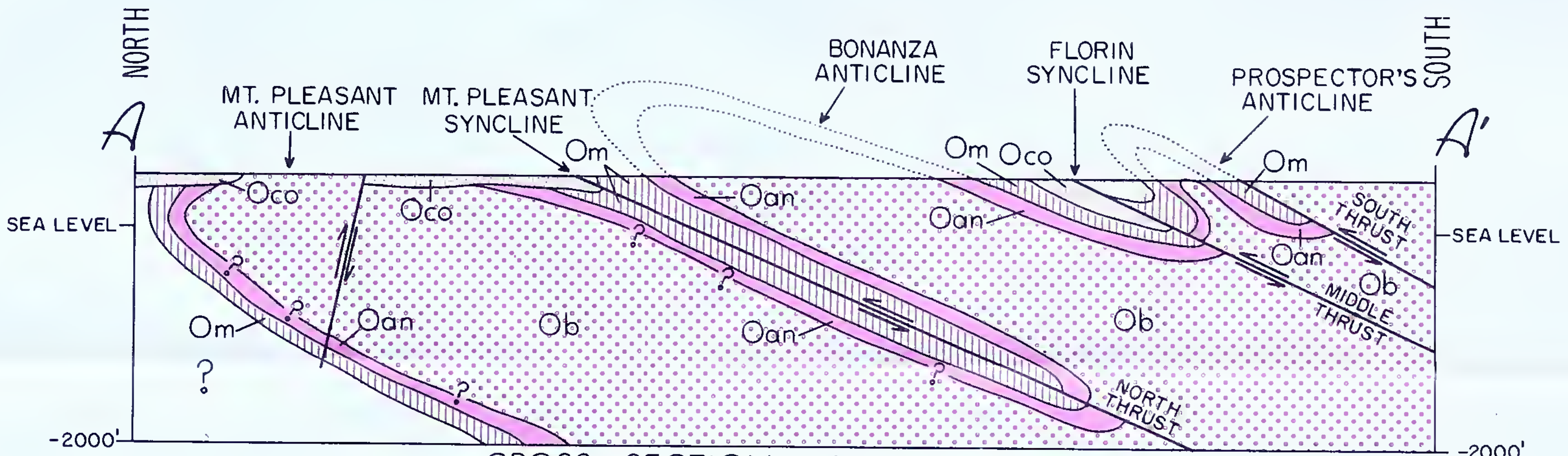

CROSS SECTION A—A'

GEOLOGIC MAP OF THE MOUNT JOY AREA, LANCASTER COUNTY, PENNSYLVANIA

by

B.J. O'Neill, Jr.

1975

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

IC 76, PLATE 1